COLLECTION OF AEROSOL PARTICLES BY ATOMIZED SPRAYS

BY

ROBERT BEVERLEY FEILD

B.Ch.E., University of Virginia, 1948
M.S., University of Illinois, 1950

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CHEMICAL ENGINEERING
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UNIVERSITY OF ILLINOIS, 1952

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Introduction

The object of this work was to study the collection of aerosol particles by atomized droplets in a venturi scrubber. Such a venturi scrubber consists of a conventional venturi into which the scrubbing liquid is introduced at the throat. A cyclone following the scrubber serves to remove the liquid droplets with the collected material. Collins (1,2) and Jones and Anthony (3) have reported successful applications of the venturi scrubber to a wide variety of aerosols. Ekman and Johnstone (4) studied the variables affecting the efficiency of the scrubber for collecting oil aerosols. Johnstone and Roberts (5) measured the overall efficiency of a venturi with a rectangular throat as a gas absorber. Tassler (6) and Feild (7) measured the volumetric and surface absorption coefficients for the absorption of sulfur dioxide in a venturi scrubber. An analysis of the forces involved in the collection of aerosol particles has been presented by Ranz (8).

In this work, it was hoped that by using aerosols of different particle size and different physical properties some idea of the relative importance of the various aerosol particle collection mechanisms could be obtained. Such knowledge would be valuable in attempting to improve the efficiency of the venturi scrubber, or to establish its practical limitations, as well as in designing new aerosol collecting devices.

Theory

The factors that may affect the efficiency of collection of aerosol particles by spray droplets in an aerosol stream are:

1. Particle inertia
2. Electrostatic attraction
3. Random molecular motion of Brownian diffusion
4. Thermal gradients between the particles and the droplets

In the first case, a particle carried along by an air stream on approaching a spray droplet tends to follow the streamlines but may strike the droplet because of its inertia. In the second case, the particles may be caused to impact upon the droplets by actual or induced electrostatic forces. In the third case, the particles may be so small that molecular bombardment imposes an erratic motion on their paths increasing the chance of impaction on the droplets. In the fourth case, this random motion may be increased by the existence of a thermal gradient between the particles and the spray droplets.

Dimensionless parameters, which are basically comparisons of the various forces tending to cause impaction with the fluid resistance opposing particle motion, are used by Ranz (8) to compare the relative importance of the forces. The dimensionless parameter characterizing the effect of inertia ψ is defined by

$$\psi = C_c \rho_p V_o D_p^2 / 18 \mu D_c$$

where C_c is an empirical correction factor for resistance of fluids to the movement of small particles, ρ_p is the particle density, V_o is the velocity of the particle relative to the droplet, D_p is the diameter of the particle, μ is the viscosity of the gas, and D_c is the diameter of the spray droplet. The dimensionless parameter characterizing the effect of electrical attraction by charges, K_E, is defined by

$$K_E = C_c q_p q_{ac} / 3\pi\mu\epsilon_o D_p V_o$$

where q_p is the electrical charge on the particle, q_{ac} is the charge per unit area of drop surface and ϵ_o is the permittivity of free space. The dimensionless parameter characterizing the effect of electrical attraction by induction, K_I, is defined by

$$K_I = 2C_c(\epsilon_1 - \epsilon_2) q_{ac}^2 D_p^2 / 18\mu\epsilon_o D_c V_o$$

where ϵ_1 is the dielectric constant of the particle, and ϵ_2 is the dielectric constant of the gas. The dimensionless parameter characterizing the effect of Brownian diffusion, θ, is defined by

$$\theta = C_c kT / \mu D_c D_p V_o$$

where k is the gas constant, and T the absolute temperature. The dimensionless parameter characterizing the effect of a thermal gradient between a particle and a spray droplet, K_T, is defined by

$$K_T = 3/2\ (H_g/2H_g + H_p)\ (\mu/\rho T)\ (dT/dx)\ (1/V_o)$$

where H_g is the thermal conductivity of the gas and H_p is the thermal conductivity of the particle.

Comparison of the dimensionless parameters shows that only the inertial mechanism is favored by the high relative particle velocity produced in the venturi throat. Only the inertial and electrical attraction by induction mechanisms are favored by increased aerosol particle size. Increased particle density increases only the inertial effect. In general the smaller the diameter of the spray droplet the more effective the particle collection.

Experimental

The venturi used in this work was placed in a 3-inch pipe line. The convergent section had a total included angle of 25°. The throat was 1½ inches long and the inside diameter was 1½ inches. The angle of the divergent section was 7°. The water was injected at the throat of the venturi from four radial holes in a concentric tube.

Three aerosols were used. Ammonium sulfite and ammonium chloride fumes were used as water soluble aerosols. Dibutylphthalate smoke was used as an insoluble aerosol. The solid aerosols were produced by mixing an excess of sulfur dioxide, or hydrogen chloride, with ammonia in the air stream before it reached the venturi. The dibutylphthalate aerosol was produced by vaporizing the liquid and then allowing it to condense in air containing sodium chloride nuclei.

Radial profiles of the liquid collection rate and the amount of aerosol in the liquid were taken at two inch intervals along

the divergent section of the venturi. These were used to calculate the amount of aerosol collection by the liquid up to that distance from the point of liquid inlet. A colorimetric analysis for ammonia with Nessler's reagent was used to determine the amount of ammonium salt aerosols present in the liquid samples. When dibutylphthalate formed the aerosol, the quantity present was determined by ultra-violet spectrophotometric analysis. The size distributions of the aerosols were determined by a high velocity impactor (9). A Millikan cell was used to measure the naturally occurring charge on the ammonium salt aerosols. The dibutylphthalate aerosol was artifically charged by passing it through a high voltage corona discharge. The electrostatic charge on the water droplets that impacted on two different size brass cylinders placed in the air line was estimated.

The volume-surface mean diameters of the ammonium sulfite, dibutylphthalate, and ammonium chloride aerosols were 1.22 microns, 0.58 microns, and 0.27 microns, respectively. The ammonium salt aerosols had approximately one tenth their particles charged to approximately one twentieth the maximum possible charge while the spray droplets had less than their maximum possible charge. The liquid feed rate was varied from 0.23 gal. per 1000 cu. feet of gas to 0.67 gal. per 1000 cu. ft. The throat velocity and the spray droplet mean diameter were kept constant in this work.

The collection efficiency was found to increase with increasing particle diameter and with increasing liquid rate in the range covered. The rate of particle collection was greater than the rate of gas absorption at positions close to the throat of the venturi but was less than the rate of gas absorption at positions near the end of the venturi. The data of this work were successfully correlated on the basis of the inertial mechanism. The data of Ekman and Johnstone (4) for the collection of dibutylphthalate aerosols with varying throat velocities, spray droplet diameters, and liquid rates were also successfully correlated with the results of this work on the same basis. The collection efficiency was increased about ten

per cent by charging the dibutylphthalate aerosol.

The values of the dimensionless parameters characterizing the various collection mechanisms were calculated at the venturi throat. The inertial parameter was 1000 times the value of the parameter characterizing the effect of electrical attraction which was in turn 10 times the parameter characterizing the effect of electrical attraction by induction. The parameters characterizing the effect of random molecular motion and the effect of a thermal gradient were, respectively, 10^{-6} and 10^{-9} times the value of the inertial parameter.

Conclusions

The relative magnitude of the dimensionless parameters indicates that, close to the throat of the venturi where a high relative particle velocity exists, inertial impaction is the dominating mechanism for particle collection. The success obtained in using the inertial mechanism to correlate the results of this work confirms this conclusion. As the dibutylphthalate aerosol collection could be correlated with the ammonium salt aerosol collection on the basis of the inertial mechanism of collection, it was concluded that the nature of the aerosol material is essentially immaterial in the performance of the scrubber. Only a minor increase in the collection efficiency was obtained on charging the particles as the theory predicts.

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VITA

Robert Beverley Feild was born on May 18, 1925, in Wilkes-Barre, Pennsylvania. He attended public schools in Charles Town, West Virginia, and Roanoke, Virginia. After graduating from Jefferson Senior High School in Roanoke, Virginia, in 1942, he entered the University of Virginia. From 1945 to 1946 he served in the United States Navy. In 1946, he returned to the University of Virginia and received the Degree of Bachelor of Chemical Engineering in June 1948. He entered the Graduate College of the University of Illinois in 1948 and received the Degree of Master of Science in February 1950. He held a half-time graduate assistantship from September 1948 to June 1949 and a half-time Research Assistantship in the Engineering Experiment Station from June 1949 to August 1951. He is a member of The Raven Society of the University of Virginia and of Tau Beta Pi and Sigma Xi.